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Comparison of isokinetic and isoinertial lifting tests as predictors of maximal lifting capacity

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Summary. This study compared the relationship between isokinetic lifting test (ILT) performance and a maximal operational lifting test (OLT) with that between an isoinertial progressive lifting test (PLT) and OLT. Fifty subjects performed the ILT, PLT and OLT after familiarization trials. OLT was defined as the weight of the heaviest crate that could be lifted to 1.34 m with a progressive, incremental test. ILT performance was the force generated during a single maximal simulated lift on an isokinetic dynamometer. PLT performance was the maximal weight lifted to 1.52 m with a progressive, incremental protocol on a weight stack. OLT was highly correlated with ILT ($r=0.96$) and PLT ($r=0.97$); the standard error was similar for both linear regression equations. The results demonstrate that a single maximal voluntary lift on an isokinetic dynamometer is as good a predictor of OLT as in the PLT presently used in military recruit centers.

Key words: Muscle strength – Ergometry – Occupational – Military – Lifting

Introduction

The development of simple and expedient means of evaluating lifting strength is integral to the establishment of occupational physical selection standards for both military and industrial environments. Numerous studies have been carried out in which physical performance test results, including the maximum isometric, isoinertial and/or isokinetic strength of various muscle groups, have been correlated with tests of maximum lifting capacity (Asmussen 1967; Nordesjö and Schéle 1974; Chaffin et al. 1978; Arnold et al. 1982; Kamon et al. 1982; Wright et al. 1984; Aghazadeh and Ayoub 1985; Karwowski and Mital 1986; Mital et al. 1986). For example, in Sweden all military conscripts perform a test battery which includes maximum voluntary isometric strength measurements during handgrip, knee extension and elbow flexion. Based on these scores, minimum strength requirements have been set for each of the hundreds of military job classifications (Nordesjö and Schéle 1974). The use of such static strength standards to predict dynamic lifting capacity is questionable, however, particularly in light of the results of studies documenting higher correlations between dynamic and lifting strengths than between static and lifting strengths (Kamon et al. 1982; Mital et al. 1986).

Several studies have reported fairly good correlations between isoinertial progressive lifting test (PLT) performance and actual maximum lifting capacity (Sharp et al. 1980; Kroemer 1983; Wright et al. 1984; Nottrodt and Celentano 1984). The PLT typically involves lifting a progressively heavier weight stack to a predetermined height, and performance is evaluated as the heaviest weight that can be lifted (Sharp et al. 1980; McDaniel et al. 1983; Nottrodt and Celentano 1984; Jetté et al. 1987). The sensitivity of such a test is limited, however, by the minimum weight increment that can be added to the weight stack. In addition, muscular fatigue may confound the evaluation of lifting strength with such a PLT because the number of lifts required to determine maximum performance may vary greatly among subjects. Subjects requiring more lifts will be more likely to be affected by fatigue, thus confounding the prediction of their lifting capacity (Jiang and Ayoub 1987).

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The problems described above would be avoided during isokinetic lifts where maximal voluntary force generation can be registered during a single lift if strength is to be evaluated, or during repeated lifts if muscular endurance is of interest. Pytel and Kamon (1981) demonstrated that peak force generated during a single maximal isokinetic lifting test (ILT) correlated better with operational lifting test (OLT) performance than did maximum isometric strength of the elbow flexors or back extensors. Similar results were reported by Mital et al. (1986), while Aghazadeh and Ayoub (1985) reported less absolute error when predicting dynamic lifting capacity from isokinetic rather than static strength. Since the experimental design of the studies which employed an ILT did not include a PLT, it is not possible to determine whether an ILT is a better predictor of OLT than is a variable resistance PLT.

The purpose of the present study was to compare the interrelationships between the ILT, PLT, and OLT protocols.

Methods

Subjects. Fifty students (28 females and 22 males) from a local community college volunteered to participate as subjects after being fully informed about the purpose, procedures, risks, and possible discomforts associated with the experimental protocol. Some descriptive characteristics are shown in Table 1.

Procedures. The subjects performed the ILT, the PLT and the OLT on two occasions, separated by 24 h. The ILT and PLT were performed in the morning and the OLT was performed in the afternoon. The order of performing the ILT and PLT was balanced among subjects. On the day prior to the first experimental day, the subjects received standardized instructions and demonstrations on proper lifting techniques for the various lifting tests. They then performed each lifting test as a familiarization trial.

Operational Lifting Test (OLT). A standard Canadian Forces medical supply box was lifted from the floor on to a table top at a height of 1.34 m, which is the height of the flatbed of a standard military 2.5 ton truck (Fig. 1a, b). The dimensions of the box were $0.61 \times 0.40 \times 0.25$ m with a handle located on each end 0.18 m from the bottom of the container. The initial weight of the box was 27.3 kg for the males and 13.6 kg for the females. Consecutive lifts were performed at 30 s intervals until the subject was unable to place the box on to the table. After each lift the subjects rated their perceived exertion according to the Borg (1962) ratings of perceived exertion (RPE). The weight of the box was increased by 4.5 kg and 2.3 kg for the males and females, respectively, until the RPE was ≥ 15. Subsequent weight increments were 2.3 and 1.1 kg for the males and females. The RPE reference point and the weight increments were arbitrarily chosen.

Table 1. Physical characteristics of the subjects

	Males			Females		
	Mean	SD	Range	Mean	SD	Range
Weight (kg)	81.0	10.5	60–105	65.6	9.6	51–89
Height (m)	1.80	0.7	1.65–1.96	1.66	0.7	1.54–1.82
Age (y)	20.5	1.4	19–25	20.3	2.4	18–30

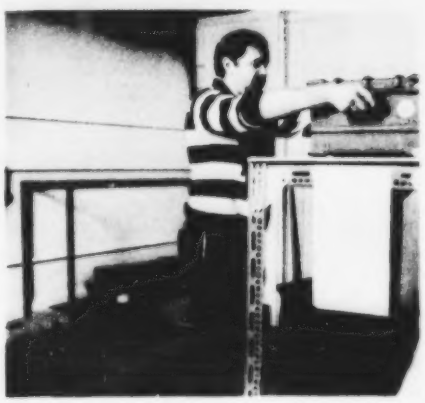

Fig. 1a, b. Performance of the operational lifting test (OLT)

Progressive Lifting Test (PLT). An incremental lifting machine (ILM), built according to Aume (1984), was used to determine the maximum weight each subject could lift to a height of 1.52 m using procedures that have been described previously (McDaniel et al. 1983; Nottrodt and Celentano 1984; Jetté et al. 1987). Briefly, the subjects lifted the handles of the ILM from their starting position, 0.305 m from the floor, to the required height in one continuous movement (Fig. 2a, b). The starting weights, weight increments, and time between lifts were as described above for the OLT.

Lift Evaluation. The following guidelines were used to determine the acceptability of a lift performed during the OLT and the PLT (McDaniel et al. 1983; Nottrodt and Celentano 1984):

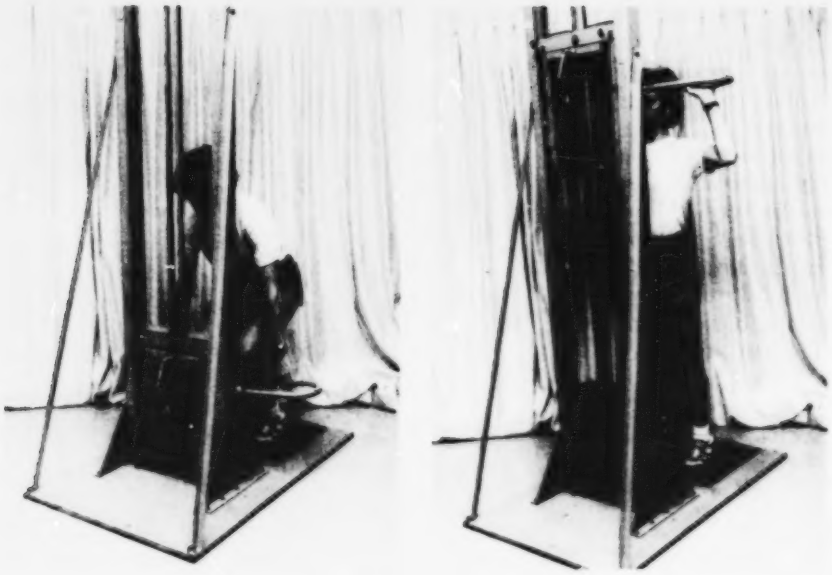

Fig. 2a, b. Performance of the progressive lifting test (PLT)

a) inability to place the medical box on the platform during the OLT, or to lift the weight to the specified height during the PLT;
b) marked hyperextension of the trunk;
c) degeneration of smooth lift into jerky segments;
d) deterioration of straight back form into thoracolumbar flexion;
e) voluntary cessation by the subject.

The same investigator evaluated all lifts throughout the experiment.

Isokinetic Lifting Test (ILT). The peak and average forces generated during an isokinetic lift to a height of 1.52 m were measured on the Ariel Computerized Exercise System Multi-Function Unit (ACE). The validity and reliability of the force measurements and control of angular velocity have been reported previously (Jacobs and Pope 1986). The subjects were instructed to lift with a style that was identical to that used for the PLT (Fig. 3a, b). After standard stretching exercises, maximal lifts were performed at angular velocities of 0.17, 0.52, and 0.79 rad·s^{-1} (10, 30, and 45°·s^{-1}, respectively). For purposes of comparisons with other studies, a conversion to linear velocities yields 0.024, 0.073 and 0.110 m·s^{-1}, respectively. These velocities refer to the dynamometer lever arm, not to the velocity of the anatomical axis of rotation. The length of the lever arm was a constant 1.40 m for all subjects from the axis of rotation to the point of force application on the handles. Generating force against hydraulic resistance is a new experience for most subjects, therefore possible learning effects were examined by having the subjects perform three maximal lifts at each velocity. The first lift was performed followed by a one min rest, and then the remaining two repetitions were done with a 30 s interval between lifts. The subject then rested for two min before lifting was tested at the next angular velocity. Day to day variation was evaluated by having the subjects perform these procedures on two consecutive days. The order of testing was at 0.17, 0.52 and then 0.79 rad·s^{-1} on the first day; the order was reversed on the second test day. Foot position

Fig. 3a, b. Performance of the isokinetic lifting test (ILT)

Table 2. Results of the operational lifting test (OLT), the isoinertial progressive lifting test (PLT) and the isokinetic lifting test (ILT)

Test	Velocity	Units	Males			Females		
			Mean	SD	Range	Mean	SD	Range
OLT	uncontrolled	kg	47.7	7.8	29.5–65.9	24.0	3.5	15.9–29.6
PLT	uncontrolled	kg	61.8	11.2	36.4–81.8	31.3	4.9	21.6–42.0
ILT	0.17 rad·s^{-1}	peak, kg	148.5	24.6	95.0–182.7	89.7	16.7	54.1–126.4
		average, kg	89.9	14.0	53.6–115.0	53.2	9.4	30.9–75.0
	0.52 rad·s^{-1}	peak, kg	132.1	23.3	69.6–168.2	82.4	17.1	51.4–108.2
		average, kg	75.3	12.0	42.7–96.0	41.4	8.0	27.7–57.3
	0.79 rad·s^{-1}	peak, kg	104.4	20.0	44.1–133.6	60.7	11.9	37.3–82.7
		average, kg	57.5	9.3	26.8–70.5	31.0	5.4	23.2–42.7

relative to the lever arm of the ACE remained constant during each lift and was standardized from trial to trial, and from day to day. Although the work produced is in the form of torque, we have expressed the force production in kilogram units because of the constant length of the lever arm, facilitating comparison with the other tests and other studies.

Data analysis. Analysis of variance (ANOVA) procedures were used to evaluate the significance of gender and test day on performance of the three lifting tests. The significance of differences in force produced during the three repetitions at a single angular velocity of the ILT were also evaluated with an ANOVA. Day to day reproducibility was evaluated with Pearson correlation coefficients and coefficients of variation calculated according to Sale and Norman (1982). Pearson correlation coefficients were calculated between the PLT and the OLT, and between the ILT and the OLT; stepwise multiple linear regression techniques were used to calculate the multiple correlation coefficients for these relationships with body weight and gender as additional independent variables. The gender variable was coded as either '1' for males or '2' for females. An ANOVA was used to evaluate whether the slopes and/or the intercepts for these relationships were significantly different between the males and females. BMDP statistical software (Dixon 1981) was used for data analysis.

Results

Test reproducibility

Results for each of the three tests are shown in Table 2. Performance of each of the lifting tests was highly reproducible from day to day and is shown in Figs. 4, 5, and 6. The coefficients of variation between the two test days were 5.9% and 7.2% for the OLT and the PLT, respectively; the values for the ILT at 0.17, 0.52 and 0.79 rad·s^{-1} were 7.8%, 10.8%, and 7.2%, respectively. The ANOVA confirmed that there were no significant differences in force among the three repetitions at each of the angular velocities during the ILT. Therefore ILT performance data in subsequent analyses refer to the strongest lift at each velocity.

Correlations

The ACE is programmed to sample force during isokinetic movement at a frequency of 16,000 Hz (manufacturer's specification), enabling the determination of both peak force and average force generated through the entire range of motion for each lift. The average force produced through the range of motion of a single isokinetic lift was more highly correlated with the OLT than was the peak force. Therefore average force generated during the lift was chosen as the criterion variable from the ILT. OLT performance was highly correlated with both the PLT and the ILT (Figs. 7, 8; Table 3). The correlation coefficients between the ILT peak forces at 0.17, 0.52 and 0.79 rad·s^{-1} were 0.94, 0.96, and 0.96, respectively. These coefficients were not statistically different from each other, therefore only the 0.52 rad·s^{-1} results are shown in Figure 8.

The ANOVA showed that there was a significant gender difference for the regressions of either ILT or PLT performance on OLT performance (Table 3). When gender and body weight were incorporated as independent variables in addition to either ILT or PLT performance, The R^2 value for the prediction of OLT performance increased minimally, from 0.93 to 0.95 (Table 4).

Discussion

The main finding in the present study was that a single maximal voluntary lift on an isokinetic dynamometer is as good a predictor of OLT per-

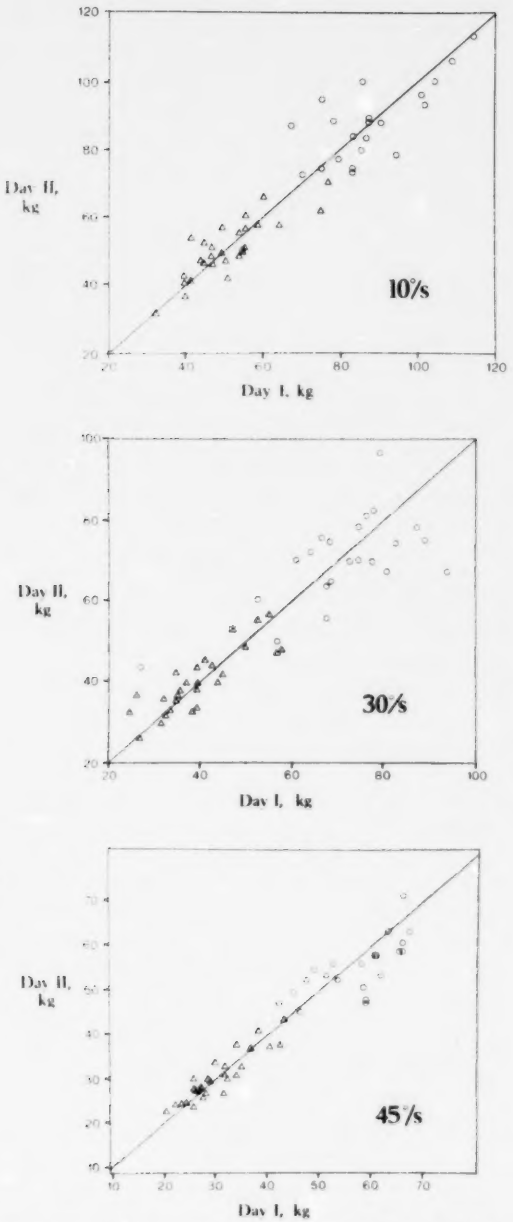

Fig. 4. Reproducibility of average torque generated during the maximal isokinetic lifting test (ILT) performed on two days with the dynamometer lever arm movement limited to the following maximal angular velocities: **(a)** 0.17 rad·s^{-1} (10°·s^{-1}), **(b)** 0.52 rad·s^{-1} (30°·s^{-1}), and **(c)** 0.79 rad·s^{-1} (45°·s^{-1}). The male (○) and female (△) data are differentiated and the line of identity is shown

formance as is a PLT consisting of repeated lifts of progressively increasing weights. The OLT performance was more highly correlated with PLT performance in the present study compared to an

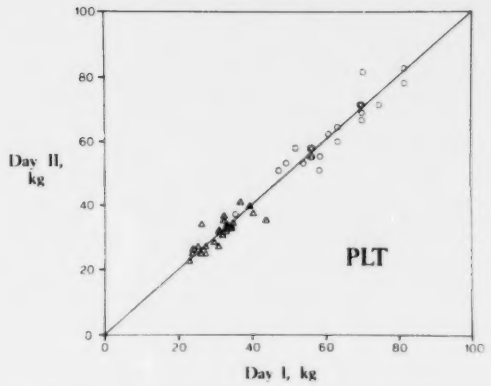

Fig. 5. Reproducibility of the maximal weight lifted during the isoinertial progressive lifting test (PLT) performed on two days. The male (○) and remale (△) data are differentiated and the line of identity is shown

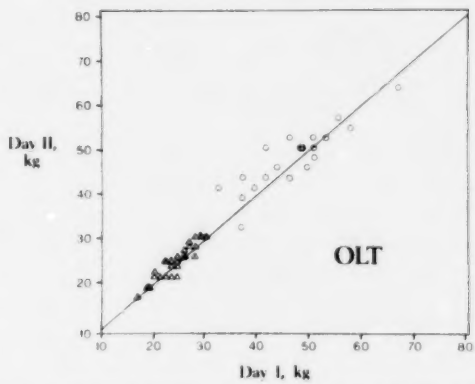

Fig. 6. Reproducibility of the maximal weight lifted during the operational lifting test (OLT) performed on two days. The male (○) and female (△) data are differentiated and the line of identity is shown

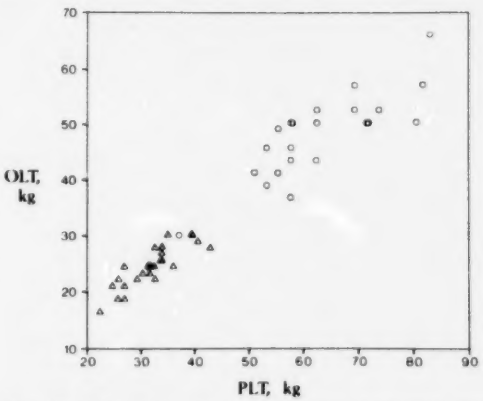

Fig. 7. The relationship between the isoinertial progressive lifting test (PLT) performance and the operational lifting test (OLT) performance. The male (○) and female (△) data are differentiated

Table 3. Linear regression equations to predict operational lifting test performance (kg) from maximal isokinetic lifting test (ILT) average force generated during lifts at 0.52 rad·s^{-1} and from the progressive lifting test (PLT) performance

Independent variable	Group	n	r	Standard error of estimate	Intercept	Coefficient
ILT (kg)	all subjects	50	0.96	7.88	−2.015	0.65
	males	22	0.88	8.21	4.49	0.58
	females	28	0.79	4.84	9.72	0.35**
PLT (kg)	all subjects	50	0.97	7.70	1.63	0.73
	males	22	0.83	9.91	12.00	0.58
	females	28	0.86	4.03	4.95	0.61*

** Significant difference between male and female regressions, $p = 0.0001$
* Significant difference between male and female regressions, $p = 0.017$

earlier report (Nottrodt and Celentano 1984) which used the same PLT protocol. Perhaps our use of a specific RPE as a criterion to begin using smaller weight increments permitted a greater resolution in scores among subjects, thus increasing the strength of the correlation.

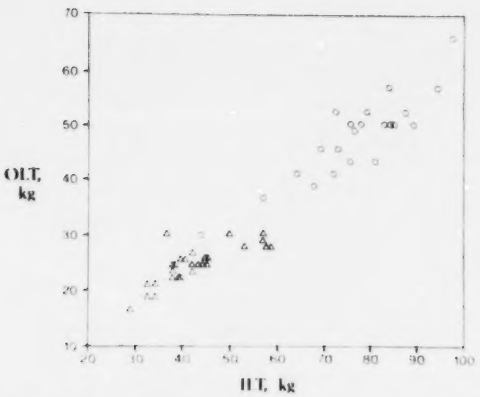

Fig. 8. The relationship between the isokinetic lifting test (ILT) performance and the operational lifting test (OLT) performance. The male (○) and female (△) data are differentiated

Table 4. Stepwise regression summary table for calculation of operational lifting test performance from either isokinetic lifting test performance (ILT), or progressive lifting test performance (PLT). Performance is expressed in kg

Step No.	Variable added to regression	R	R^2	Residual mean square
1.	ILT	0.96	0.93	28.24
2.	gender	0.97	0.95	21.58
3.	body weight	0.98	0.95	19.34
1.	PLT	0.97	0.93	26.92
2.	gender	0.97	0.94	23.08
3.	body weight	0.98	0.95	19.71

Between 92% and 94% of the variation in performance of the OLT could be explained by variation in performance of either the ILT or the PLT. It should be noted, however, that there was a significant gender difference for the regression equations used to predict OLT performance for both lifting tests. The correlation coefficients are much higher than those reported in other studies which have evaluated both isokinetic-like and lifting strength (Pytel and Kamon 1981; Kamon et al. 1982; Aghazadeh and Ayoub 1985; Mital et al. 1986). The present study used substantially different equipment and test procedures which may account for the markedly improved ability to predict lifting performance. The validity of the velocity control and force measurements with the ACE, used for the ILT in the present study, is documented (Jacobs and Pope 1986). No similar data were found for the Super Mini Gym, a clutch controlled unit, employed as the isokinetic-like test device in several studies (Pytel and Kamon 1981; Kamon et al. 1982; Mitel and Vinayagamoorhty 1984; Mital et al. 1986; Karwowski and Mital 1986), although Kamon and Pytel (1982) do state that the speed of motion was measured with an electronic speed indicator. In contrast with the clutch control of an uncoiling rope to control the velocity of the latter dynamometer, the ACE is computer controlled; a stepper motor sets a hydraulic valve aperture according to a position potentiometer sampled at an extremely high rate (16 kHz). The potential differences between the apparati used is exemplified in the report by Karwowski and Mital (1986) that peak force exerted during an isokinetic lift at 0.75 m·s^{-1} was only about 67% of the peak value recorded in the present study at a similar velocity. The subjects were of similar weight and height.

Additionally the OLT in the present study was indeed a test of lifting strength since it required that the subjects progressively lifted heavier crates until they were unable to successfully complete a lift. This protocol differs substantially from the Maximum Acceptable Lift (MAL) test employed by others, where the subjects are given time to select the maximum weight they think they could lift for an eight hour work period without becoming exhausted or overheated. It is therefore not so surprising that our muscular strength results from both the ILT and the OLT were more highly correlated with the OLT, a test of lifting strength, than the relationship of isokinetic strength to the MAL (Kamon et al. 1982; Aghazadeh and Ayoub 1982; Mital et al. 1986), a test which would seem to demand more muscular endurance than strength.

Since both the ILT and PLT tests are equally good predictors of OLT performance, consideration should be given to other factors associated with mass testing before a choice of a suitable screening test for lifting capacity is made. Chaffin et al. (1978) emphasize the following considerations when evaluating strength testing procedures: safety, time required for test performance, test reliability, and that the test be a 'reasonable' simulation of the job strength requirements. With regard to the latter consideration, both the PLT and ILT are superior to isometric strength testing because they are dynamic tests, with an inertial component, recruiting several large muscle groups, as does load lifting.

Several advantages, however, are associated with an isokinetic strength test. A military recruit center performing mass strength testing would greatly increase the number of tests completed per unit time by using an ILT compared to a PLT which requires several minutes to complete. An ILT would seem to be a safer test than a PLT because the ILT is performed in a concentric mode only, against hydraulic resistance. If a subject wants to stop generating force in the middle of an isokinetic lift, perhaps because of muscle pain, an immediate relaxation of the musculature is possible. In contrast, the weight stack used with incremental isoinertial lifts forces a subject to lower the weights with eccentric contractions, prolonging contraction time and therefore potentially increasing the risk of further damage to muscle or other tissues that may already be damaged.

A potential disadvantage of the ILT is that operational lifting is an isoinertial task, similar to the PLT, in contrast to the isokinetic nature of the ILT. Another disadvantage associated with the ILT employed in the present study, or that of Aghazadeh and Ayoub (1985), is the technological sophistication of the equipment, which may require prolonged training of prospective test administrators. Research and development of isokinetic dynamometry is rapidly advancing and there are several alternatives to the dynamometer used in this study. For example, although data about the accuracy of the apparatus have not yet been published, Pytel and Kamon (1981), Mital and Vinayagamoorhty (1984), and Karwowski and Mital (1986) reported how a much simpler, relatively inexpensive, commercially available isokinetic device could be modified to suit mass testing.

In summary, the present study provides evidence that a test of maximal isokinetic lifting strength is an excellent indicator of isoinertial lifting strength. Safety and efficiency considerations suggest that an isokinetic strength test is a viable alternative to an isoinertial test traditionally used in standardized lifting strength evaluations.

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